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Assessment of flexural properties of different grade dimension lumber by ultrasonic technique

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Abstract: The dimension lumber (45mm×90mm×3700mm) of plantation Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) was graded to four different classes as SS, No.1, No.2 and No.3, according to national lumber grades authority (NLGA) for structure light framing and structure joists and planks. The properties of apparent density was determined at 15% moisture content, bending strength and stiffness were tested according to American Society for Testing and Materials (ASTM) D198-99, and dynamic modulus of elasticity (E_{usw}) was measured by ultrasonic technique, for predicting the flexural properties of different grade lumbers. The results showed that E_{usw} was larger than the static MOE. The relationship between E_{usw} and static MOE was significant at 0.01 level, and the determination coefficients (R^2) of the four grade lumbers followed the sequence as $R^2_{No.2}$ (0.616)> R^2_{SS} (0.567)> $R^2_{No.1}$ (0.366)> $R^2_{No.3}$ (0.137). The R^2 of E_{usw} and MOR were lower than that of the E_{tru} and MOR for each grade. The E_{usw} of all the grade lumbers, except No.3-grade, had significant correlation with the static MOE and MOR, thus the bending strength of those grade lumbers can be estimated by the E_{usw}. The E_{tru} values of four grade lumbers followed a sequence as No.2-grade (10.701 GPa) > SS-grade (10.359 GPa) > No.1-grade (9.840 GPa) > No.3-grade (9.554 GPa). For the same grade dimension lumber, its E_{usw} value was larger than static MOE. Mean values of MOR for four grade lumbers follow a sequence as No.2-grade (48.67 MPa) > SS-grade (48.16 MPa) > No.3-grade (46.55 MPa) > No.1-grade (43.39MPa).

Keywords: Dimension lumber; Lumber grade; Ultrasonic technique; Dynamic modulus of elasticity; Static modulus of elasticity; Modulus of rupture

Introduction

Nondestructive technology is considered as more convenient, reliable, easy and practical method for predicting the bending strength and stiffness compared to the dead weight loading. In many countries, the nondestructive evaluation techniques have been widely used to grade and test wood structural elements such as timber, lumber and truss, etc. Oliveira *et al* (2002) found that there was high correlation between the modulus of elasticity obtained from acoustic wave and static deflection technique. Robert *et al* (2000) stated that several technologies, such as X-rays, chemical analysis, vibration technique and sound wave transmission, could be used to evaluate wood properties nondestructively. Yin *et al* (2005) evaluated the static bending elastic properties of full-size lumbers by using transverse vibration method. Huang (2006) assessed the static modulus of elasticity on clear samples of Chinese fir wood by NIR. The results showed that there existed a very close liner relationship between dynamic and static modulus of elasticity. However, no report was found on the effect of different grade specimens on the relationship between the flexural properties obtained from nondestructive method and static deflection technique.

The purpose of this study was to analyze the correlations between dynamic tests by ultrasound and static bending tests for different grade lumbers with structural dimensions, aiming to analyze the feasibility of applying the ultrasonic method to evaluate different grades of dimension lumber.

Material and Methods

Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) is a kind of unique valuable species in China. It grows very fast, upward in shape, with straight and uniform grain, easy to plant with excellent capacity to resist injury and decay. Plantation wood of Chinese fir used in this test was fell from Jiangle County in Fujian Province, 34 years old, with an chest diameter of 20 to 35 cm. The logs were sawn to dimension of 50mm×100mm and the lumbers were kiln seasoned to moisture content of 15%. They were further planed and crosscut to 45mm×90mm×3700mm. All the dimension lumbers were visually graded to four grades: Select Structural (SS), No.1, No.2 and No.3, according to visual grading technical manual of national lumber grades authority (NLGA 2003) of Canada.

The dynamic tests were conducted using ultrasound SYLVATEST equipment with 22 kHz transducers. Two readings were recorded for the wave propagation velocity. The dynamic modulus of elasticity (E_{usw}) was calculated based on the mean

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readings and the apparent density according to the following equation.

$$E_{usw}=Pv^2 \tag{1}$$

Where, E_{usw} is the dynamic modulus of elasticity, P the density of the wood, and v is the velocity of the longitudinal wave.

For the bending test, lumber was tested along edge-wise under third-point loading at a span-to-depth ratio of 18:1 according to ASTM D198-99. A yoke system was used to measure the mid-span deflection along the neutral axis. The load scope from 0.5 kN to1.5 kN was applied for bending MOE test and the average MOE values of three times was calculated according to the following equation.

$$E_{tru} = \frac{23\ pl^3}{108\ bh^3 f} \tag{2}$$

Where, E_{tru} is the static modulus of elasticity (MPa), P the load (N), l the span (mm), b the width of the specimen (mm), h the height of the specimen (mm), and f is the deflection (mm).

Results

The test results of modulus of elasticity and modulus of rupture of the four grades lumber were shown in Table 1. E_{usw} value was obtained from nondestructive test whereas E_{tru} and MOR were calculated from static bending test. Static modulus of elasticity was lower than dynamic MOE for each grade. From Table 1, it was also observed that the static MOE of No.2-grade dimension lumbers was the largest among the four grades. Mean values of static MOE for No.2, SS, No.1 and No.3 grade lumbers were 10.70, 10.36, 9.84, and 9.55GPa, respectively. In the meantime, the dynamic MOE and MOR of No.2-grade lumber were the largest among the four grades (Table 1).

Table 1. Elastic properties from dynamic and static bending of dimension lumber

Grade	Item	Mean (GPa)	Min (GPa)	Max (GPa)	STDEV. (GPa)	CV. (%)
SS n=324	E_{usw}	11.77	4.32	24.55	2.12	18.00
	E_{tru}	10.36	6.18	15.31	1.58	15.27
	MOR(×10^{-3})	48.16	17.53	95.72	12.27	25.48
No.1 n=62	E_{usw}	11.04	4.94	17.18	2.26	20.47
	E_{tru}	9.84	7.03	14.20	1.56	15.82
	MOR(×10^{-3})	43.39	21.50	73.69	11.91	27.46
No.2 n=122	E_{usw}(GPa)	12.35	5.86	16.53	1.81	14.62
	E_{tru}(GPa)	10.70	6.34	14.20	1.59	14.87
	MOR(×10^{-3})	48.67	18.75	75.07	13.14	27.00
No.3 n=73	E_{usw}(GPa)	11.21	4.61	15.95	2.55	22.78
	E_{tru}(GPa)	9.55	3.57	14.16	2.02	21.16
	MOR(×10^{-3})	46.55	13.03	74.87	13.31	28.59

The relationships between E_{usw} and E_{tru} of four grade lumbers were separately shown in Figs. 1, 2, 3, and 4. The determination coefficients of four grades were shown in Table 2 and the relationships were significant at 0.01 level. However, for No.2-grade lumber and even better grade lumber, there was a strong correlation between dynamic and static modulus of elasticity.

The relationship between E_{usw}, E_{tru} and MOR of four grades lumber are shown in Figs. 4, 5, 6, 7 and 8. For each grade, the determination coefficient of E_{usw} and MOR, ranged from 0.163 to 0.357, was lower than that of E_{tru} and MOR, ranged from 0.3128 to 0.578. Therefore, it can be concluded that there was a strong correlation between static MOE and MOR (Table 2).

Table 2. Results of regression analyses of *MOE* and *MOR* by different grades

Grade	The model of function	R^2
SS n=324	E_{tru}=0.562E_{usw}+3.739	0.567
	MOR=3.4571E_{usw}+7.4701	0.357
	MOR=5.3844E_{tru}-7.6073	0.482
No.1 n=62	E_{tru}=0.417E_{usw}+5.240	0.366
	MOR=2.178E_{usw}+19.362	0.171
	MOR=5.822E_{tru}-13.898	0.578
No.2 n=122	E_{tru}=0.692E_{usw}+2.155	0.616
	MOR=4.0264E_{usw}-1.0588	0.306
	MOR=5.5123E_{tru}-10.319	0.446
No.3 n=73	E_{tru}=0.293E_{usw}+6.271	0.137
	MOR=2.102E_{usw}+22.988	0.163
	MOR=3.681E_{tru}+11.379	0.3128

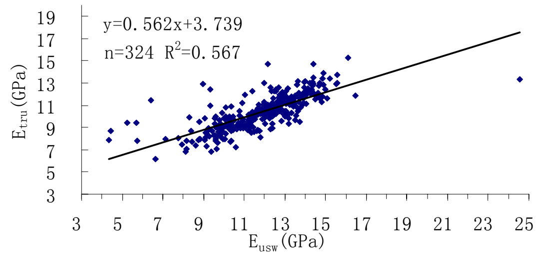

Fig. 1 Relationship of E_{usw} and E_{tru} for SS-grade lumber

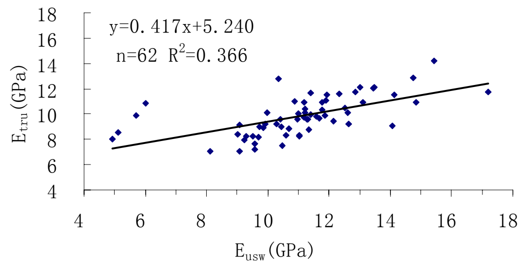

Fig. 2 Relationship of E_{usw} and E_{tru} for No.1-grade lumber

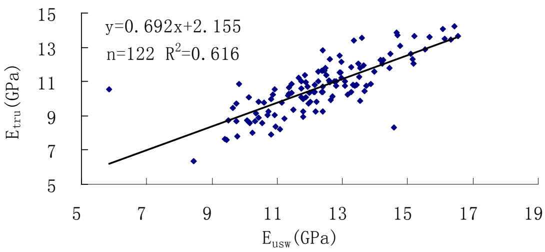

Fig. 3 Relationship of E_{usw} and E_{tru} for No.2-grade lumber

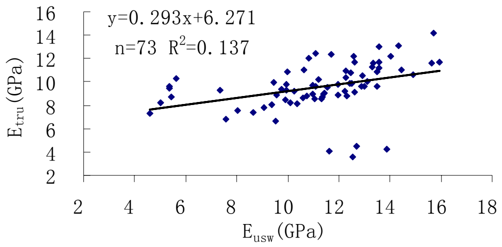

Fig 4 Relationship of E_{usw} and E_{tru} for No.3-grade lumber

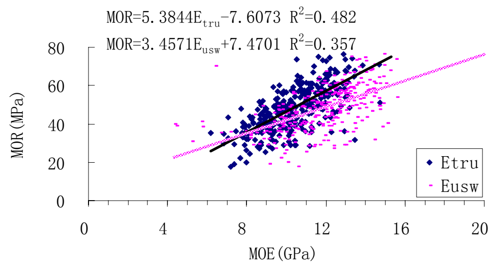

Fig 5 Relationship of E_{usw}, E_{tru} and MOR for SS-grade lumber

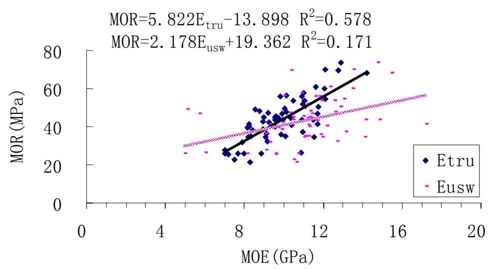

Fig 6 Relationship of E_{usw}, E_{tru} and MOR for No.1-grade lumber

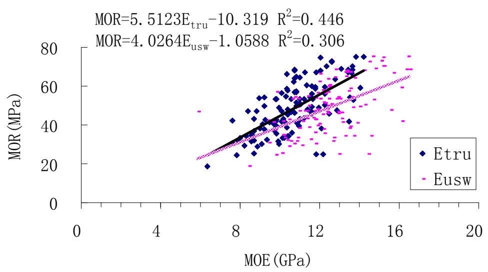

Fig 7 Relationship of E_{usw}, E_{tru} and MOR for No.2-grade lumber

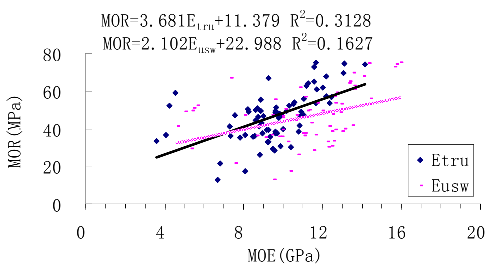

Fig 8 Relationship of E_{usw}, E_{tru} and MOR for No.3-grade lumber

Discussion

Duju *et al* (2000) tested the mechanical strength of Sarawak timber by using propagation of ultrasonic wave. The green specimens were seasoned to reach the equilibrium of moisture content, and the nominal size of sample is 50×100×2000mm. The relationship was: MOR=3.12E_{usw}+16.4, with n=185, r_{usw}=0.81; MOR=2.48 E_{tru} +34.9, with n=185, r_{tru}=0.89. It was shown that r_{usw} was lower than r_{tru}, and mean value of E_{usw} was larger than E_{tru}.

de Oliveria *et al* (2002) assessed the mechanical properties of *Pinus taeda* using an ultrasonic technique, and 33 beams with dimension of 50 × 200 × 4400mm were tested. They established the following relationship between dynamic and static MOE (E_{tru}=0.8908E_{usw}-43525 (MPa)), with r^2=0.80. The result showed that E_{usw} (6.94GPa) is larger than E_{tru} (5.75GPa).

Compared to the previous studies, this study showed that the dynamic modulus of elasticity is larger than static MOE, and the determination coefficient (R^2) of E_{tru} and MOR was larger than that of the E_{usw} and MOR, which was in agreement with the previous studies.

In this study, the static MOE of No.2-grade lumber was the largest among the four grade lumbers, followed by grade SS, No.1 and No.3, which was same as Canadian lumber properties (Barrett 1994). The dynamic MOE and MOR of No.2-grade lumber were also the largest among the four grades. This could be explained by the grading methods used in the study. The NLGA (2003) of Canada was used for the structural light framing joists and planks, which is suitable for natural grown wood. In this grade testing, the pith was permitted in every grade, and the size of knot was only one difference between SS and No.1 grades. However, as Chinese fir with wide growth ring is a plantation species, the specimens of SS and No.1 grade lumber included many of knots and high ratio juvenile wood, and about 20% lumber included pith. These defects due to plantation wood characteristics could decrease the strength of lumber greatly. Furthermore, the main defect of No.2-grade lumber was surface defect that almost does not degrade strength of lumber, for example, wane and skip (Yin 1990). In addition, the ratio of mature wood of No.2-grade lumber in this experiment was the highest among the four grades, and the ratio of pith in No.2-grade is also lower than that in other grades. The previous studied showed that MOE of mature wood was 20% higher than one of juvenile wood (Bao *et al* 1998), and there were statistically significant difference of MOE and MOR between the specimens with pith and without pith (Kretschmann *et al* 1999), thus the MOE and MOR of No.2-grade lumber is the largest among the four grades in this study.

Conclusions

Dynamic modulus of elasticity was larger than static MOE, and the coefficient of determination of E_{tru} and MOR was larger than that of E_{usw} and MOR.

The relationships between dynamic and static modulus of elasticity were significant at 0.01level for the four grades, and the coefficient of determination (R^2) of the four grade lumbers were 0.616, 0.567, 0.366 and 0.137 for No.2, SS, No.1, and No.3 grade lumbers, respectively. This suggested that the nondestructive ultrasound method could be used to obtain a reliable assess-

ment of flexural properties of No.2-grade lumber and the better grade lumber.

No.2-grade lumber showed the largest strength properties among the four grade lumbers, with the mean static MOE of 10.701 GPa (No.2), 10.359 GPa (SS), 9.840 GPa (No.1) and 9.554GPa (No.3). The mean value of MOR was 48.67Mpa for No.2-grade lumber, 48.16 MPa for SS-grade lumber, 46.55 MPa for No.3-grade lumber and 43.39 MPa for No. 1-grade lumber.

References

American Society for Testing and Materials. 2002. D 198-98. *Test method of static tests of timbers in structural sizes*, 4 (10): 59–78.

Bao Fucheng, Jiang Zehui. 1998, *Wood properties of main tree species from plantation China*. Beijing: China Forestry Publishing House.

Barrett, J.D., Lau, W. 1994. Canadian Lumber Properties. Canadian Wood Council.

de Oliveira, F.G.R., de Campos, J.A.O., Pletz, E., Sales, A. 2002, Assessment of Mechanical Properties of Wood Using an Ultrasonic Technique. In: 13th International Symposium on Nondestructive Testing of Wood, USA, 75–78.

Duju, A., Nakai, T., Nagao, H. 2000. Nondestructive evaluation of mechanical strength of sarawak timbers. In: 12th International Symposium on Nondestructive Testing of Wood, Hungary, 131–137.

Huang Anming. 2006. Modeling wood properties of Chinese fir plantation using near infrared spectroscopy. Doctoral paper, Chinese Academy of Forestry, China. (in Chinese)

Kretschmann, D.E., Evans, J.W. 1999. *Monitoring of visually graded structural lumber*. Forest Products Laboratory, United States Department of Agriculture.

Robert, R.J., Wang Xiping. 2000, Comparison of several nondestructive evaluation techniques for assessing stiffness and MOE of small-diameter logs. 12nd International Symposium on Nondestructive Testing of Wood, Hungary, 155–163.

Standard Grading Rules for Canadian Lumber. 2003. National lumber grades authority (NLGA). Approved by the American lumber standard board of review and the Canadian lumber standards accreditation board.

YIN Sici. 1990. *Wood qualify and defect*. Beijing: China Forestry Publishing House. (in Chinese)

YIN Yafang, LU Jianxiong, NI Chun, REN Haiqing. 2005. Evaluating static bending elastic properties of full- size lumbers by using transverse vibration method. *Journal of Beijing Forestry University*, **27** (5): 107–110. (in Chinese)